Anderson *et al.* reply (to the comment of Murphy on "Indication, from Pioneer 10/11, Galileo, and Ulysses Data, of an Apparent Anomalous, Weak, Long-Range Acceleration").

We conclude that Murphy's proposal (radiation of the power of the main-bus electrical systems from the rear of the craft) can not explain the anomalous Pioneer acceleration.

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In his comment [1] Murphy proposes that the anomalous acceleration seen in the Pioneer 10/11 spacecraft [2] can be "explained, at least in part, by non-isotropic radiative cooling of the spacecraft." So, the question is, does "at least in part" mean this effect comes near to explaining the anomaly? We argue it does not [3].

Murphy considers radiation of the power of the main-bus electrical systems from the rear of the craft. For the Pioneers, the aft has a louver system, and "the louver system acts to control the heat rejection of the radiating platform...A bimetallic spring, thermally coupled radiatively to the platform, provides the motive force for altering the angle of each blade. In a closed position the heat rejection of the platform is minimized by virtue of the "blockage" of the blades while open louvers provide the platform with a nearly unobsructed view of space." [4]

If these louvers were open, then, Murphy calculates this would produce an acceleration $a_0 = 9.2 \times 10^{-8}$ cm s^{-2}. Murphy uses numbers for thermal radiation that correspond to the position of the spacecraft near Jupiter, i.e., 5.5 AU. At that time, the spring temperature was about 56 ° F, meaning the opening angle of the louvers was down to 20°. This reduces his estimate for the effective a_0 to $a \equiv \sin(20^\circ) a_0 = 3.2 \times 10^{-8}$ cm s^{-2}.

However, our effect could only be seen well beyond 5.5 AU; i.e., further than 10-15 AU. By 9 AU the actuator spring temperature had already reached $\sim$40°. This means the louver doors were closed (i.e., the louver angle was zero) from there on out. Thus, from our quoting of the radiation properties above, any contribution of the thermal radiation to the Pioneer anomalous acceleration should be small. (Certainly it would not be expected to be higher than it was at a 20° opening angle [5].)

In 1984 Pioneer 10 was at about 33 AU and the power was about 105 W. (Always reduce the effect of the total power numbers by 8 W to account for the radio-beam power.) In (1987, 1992, 1996) the craft was at $\sim$(41, 55, 65) AU and the power was $\sim$(95, 80, 70) W. The louvers were inactive. No decrease in a_P was seen.

We conclude that this proposal can not explain the anomalous Pioneer acceleration.

Heat radiation should be a more significant systematic for Ulysses than for the Pioneers. However, in principle this could be separated out since accelerations along the lines of sight towards the Earth and towards the Sun could be differentiated. This is one of the reasons why a detailed calculation of the Ulysses orbit from near Jupiter encounter to Sun perihelion was undertaken, using CHASMP.

This turned out to be a much more difficult calculation than imagined. Because of a failed nutation damper, an inordinate number of spacecraft maneuvers were required (257). Even so, the analysis has now been completed. The results are disheartening. For an unexpected reason, any fit is not significant. The anomaly is dominated by (what appear to be) gas leaks. That is, after each maneuver the measured anomaly changes. The measured anomalies randomly change sign and magnitude. The values go up to about an order of magnitude larger than a_P. So, although the Ulysses data was useful for range/Doppler checks to test models, like Galileo it could not provide a good number for a_P.

The gas leaks so far found in the Pioneers are about an order of magnitude too small to explain a_P. Even so, we feel that some systematic or combination of systematics (such as heat or gas leaks) will most likely explain the anomaly. However, such an explanation has yet to be demonstrated.

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References

[1] E. M. Murphy, previous comment and eprint gr-qc/9810015.

[2] J. D. Anderson, P. A. Laing, E. L. Lau, A. S. Liu, M. M. Nieto, and S. G. Turyshev, Phys. Rev. Lett. **81**, 2858 (1998). For further details see eprint gr-qc/9903024.

[3] From the present wording of his comment, it appears Murphy does not disagree too strongly with this statement.Indeed, in a private communication from JDA to Murphy on 6 Oct. 1998, it was pointed out that the Pioneers have louvered doors and not fins as radiators. This, by itself, obviated the "prosaic explanation" of the original eprint [1] by a large factor.

[4] Pioneer Project NASA/ARC document No. PC-202.

[5] Any change of the louver angle should result in a spin change due to the thermal radiation. This is because of the orientation of the lovers around the bus on the spacecraft. We detect no such change.